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EVALUATION OF SMAW CONSUMABLES FOR REPAIR OF WELD-ZONE CORROSION

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METALS TECHNOLOGY LABORATORIES

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MICROMEDIA

EVALUATION DE BAGUETTES DE SOUDAGE POUR LA REPARATION DES ZONES DE SOUDURE CORRODEES

par

R.J. Brigham and V. Mitrovic-Scepanovic

Cinq baguettes de soudage ont été evaluées comme solution pour la réparation des zones de soudure corrodées sur les navires de la Garde Cotière Canadienne fabriqués d'aciers de type A, E et EH. La performance de ces aciers a été evaluée en utilisant le "test de réservoire" à CANMET. Une gamme de vitesse de corrosion a été observé. Deux baguettes de soudage (E55018-C3 et OK73.08) ont demontré un compatibilité avec tous les aciers incluant le type EH contenant 1.39% Mn.

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ABSTRACT

Five SMAW consumables were evaluated as candidates for repairing weld-zone corrosion in CCG ships constructed of Grade A, Grade E and Grade EH steels. Their performance was evaluated by the CANMET tank test procedure. A spectrum of corrosion rates was observed but E55018-C3 and OK73.08 were found to be compatible with all baseplates including Grade EH containing 1.39% Mn.

INTRODUCTION

The Fleet System Branch of Canadian Coast Guard, Transport Canada, owns and maintains a large variety of ships which operate in Gulf and Arctic ice conditions. The ice transiting fleet has been experiencing preferential corrosion of weld metal and, with the introduction of higher strength E and EH grade steels, can anticipate accelerated heated-affected zone attack. This accelerated corrosion over a period of time requires recurring repairs throughout the operational life of an icebreaking ship.

A contract, funded by the Canadian Coast Guard, was initiated to identify the optimum welding consumables and welding parameters to repair corroded welds. The study, as defined jointly by Coast Guard and CANMET, included electrochemical and metallographic evaluation of three shipbuilding steels containing original submerged-arc weldments which were "repaired" with five different SMAW consumables (1) at two heat input levels.

Complementary evaluation of the corrosion characteristics of the same welds was performed by tank testing at CANMET of specimens manufactured by the CCG Contractor. The results obtained at CANMET are presented in this report.

EXPERIMENTAL

Three steels [Grade A, Grade E, and Grade EH (Table 1)] were used as baseplate material. Initially the 25 mm plates were welded with an EL12/F4803 wire/flux combination (Table 2). The baseplate combinations were A/A, E/E, EH/EH, A/E and E/EH. The original welds were first machined to a depth of 6 mm and then "repaired" with E48018-1, OK73.08, E55018-C1, E55018-C3 and

E48018RCR consumables (Table 2). For each of the baseplate/repair consumable combinations, two welding techniques were used: a weave technique with nominal heat input of 5.7 kJ/mm and a stringer technique with nominal heat input of 1.8 kJ/mm (see Ref. 1 for welding data sheets).

A total of 48 trapezoidal specimens were subjected to tank testing (2) for six months in 3.5% NaCl solution at nominally 1-2 C but with inadvertent short excursions to higher temperatures. The samples were taken out of the tank at two-month intervals; the corrosion products were removed by wire brushing; and depth of attack of the baseplate, weld metal and heat-affected zone were measured with a profilometer. In addition, a micrometer was used to confirm the depth of HAZ attack over the whole length of the weld after 6 months of exposure. The maximum depth of attack was used as a criterion for the degree of corrosion.

RESULTS

Weld Metal Corrosion

The rates of weld metal corrosion are given in Table 3 and Fig. 1. As shown in Table 3, differences in heat input equivalents caused only small differences in weld-metal corrosion rates. No galvanic effects resulting from A/E or E/EH plate combinations were noted. Consequently the data were averaged for both low and high heat input equivalents on all base plates and plotted as a function of time (Fig. 1). The average corrosion rates differ significantly for different weld metal compositions, particularly due to differences in Cu and/or Ni content as already shown by Brigham (2).

While the relative resistance of SMAW consumables common to this and the previous study by Brigham shows the same order, i.e., 48018-1 < OK73.08 < 55018-C1, there are significant differences. The most striking difference is the magnitude of the attack of both the weld metals and the baseplates. For example, in the earlier study (2), the baseplate was attacked to a maximum depth of approximately 0.2 mm and 48018-1 to a depth of approximately 1.6 mm after 6 months of nominally the same exposure conditions as in this test. The 2.5 to 6-fold increase in rates in this test has been traced to a different attack morphology resulting from short excursions to higher temperatures. In a series of experiments on similar steels (without welds), it was shown that by increasing the test temperature to values greater than approximately 20 C even for short times, the planar morphology characteristic of low temperature testing breaks down into a series of ridges in a swirl pattern. Figure 2 shows an example of this ridge morphology which developed in one week of exposure at 30 C.

Early in this series of tank tests, the plates were subjected to temperature excursions amounting in total to a few hours because of equipment malfunctions. This amount of time at higher temperature was clearly sufficient to cause the onset of the non-planar attack morphology. Although the quantification of weld-zone corrosion is more difficult with specimens showing this morphology and the kinetics of attack are not linear with time as shown in Fig. 1, the resulting high degree of roughness corresponds very closely to the morphology observed on ships which have operated in Arctic ice conditions. Figures. 3 and 4

show the most and the least corrosion resistant weldments, i.e., 48018RCR (Samples 11A & B) and 48018-1 (Samples 1A & B) respectively, after 4 months exposure. Note the high degree of roughness over the whole plate and the remnants of the swirl patterns in the welded areas at the tops of samples 11A & B and the bottom of sample 11A.

The remarkable corrosion resistance of E48018RCR cannot be attributed solely to the level of alloying with Cu and Ni because these values are similar to those of OK73.08. The low Si concentration (0.14%) compared with the higher levels (>0.35%) in the other consumables is believed to be at least partly responsible in a way analogous to that for baseplate Si levels demonstrated by Rasanen and Relander (3). This effect of alloyed Si in both base plates and weldments is under further investigation.

HAZ Corrosion

Heat-affected zone corrosion is generally observed when the corrosion resistance of the weld metal is superior or equivalent to that of the baseplate. This type of corrosion has been associated with low temperature transformation products formed during cooling after welding and was found to be a function of Mn-content of the base plate as well as of the heat input equivalent.

In the present study, preferential HAZ corrosion was observed only for Grade E and Grade EH steels in combination with most corrosion resistant consumables (Table 4, Fig. 5). No unusual effects of A/E or E/EH baseplate combinations were noted. In Fig. 3, an example of HAZ attack can be observed. The results

confirm that the baseplate steel containing more than ~1% Mn is susceptible to this type of attack (2). The effect of heat input equivalent was not found to be pronounced with the exception of 48018 RCR electrode, where HAZ corrosion increases with lower heat input for both types of baseplate steel, i.e., Grades E and EH.

These results show clearly that by choosing a repair electrode with intermediate corrosion resistance (such as 55018-C3 or OK73.08) an acceptable match can be achieved without significant HAZ attack.

SUMMARY

1. A spectrum of corrosion rates of weld metals used for repair was observed. This spectrum depended primarily on the Cu and/or Ni contents of the weld metal.
2. Heat-affected zone corrosion was observed in high Mn plates (Gr. E and Gr. EH) in combination with most resistant repair electrodes (48018RCR and 55018-C1).
3. The repair electrodes most compatible with Gr EH baseplate steel are 55018-C3 and OK73.08.

REFERENCES

1. AMCA Report no. 7-185-170.
2. R.J. Brigham, "Corrosion of Welds in Icebreaking Ships", Marine Engineering Digest 6, 29 (1986).
3. Rasanen, E. and Relander, K. "Development of Shipbuilding Steel Plates for Use on Arctic Seas", Scand. J. Metall 7, 11 (1978).

Table 1: Chemical composition (spectorgraphic analysis) and mechanical properties (mill test report) for as-received steels

Composition, %						Mechanical Properties		
Steel	C	Mn	Si	Ni	Cu	YS MPa (ksi)	UTS MPa (ksi)	% Elongation
Gr A	.19	.47	.19	.02	.02	266 (38)	432 (62)	28
Gr E	.10	1.15	.20	.02	.02	299 (43)	439 (64)	39
Gr EH	.18	1.39	.41	.16	.31	399 (58)	555 (80)	24

Table 2: Chemical composition of undiluted weld metals (spectrographic analysis)

	C	Mn	Si	Cu	Ni	Cr
SMAW OK73.08	.074	1.27	0.46	.350	0.55	0.70
SMAW E48018-1	.057	1.60	0.62	.030	0.03	.050
SMAW E55018-C1	.061	1.13	0.37	.030	1.95	.040
SMAW E55018-C3	.055	0.80	0.39	.020	0.75	---
SMAW CLA E48018RCR	.050	0.93	0.14	.530	0.58	.040
SAW EL12/F4803	.035	1.85	1.12	.065	0.02	.045

TABLE 3: Depth of weld metal corrosion (mm)

	2 Months		4 Months		6 Months	
	Average	A&B Average	Average	A&B Average	Average	A&B Average
A	1.18		2.57		3.33	
48018-1		1.29±0.14		2.68±0.20		3.49±0.32
B	1.40		2.79		3.66	
A	0.90		1.78		2.25	
55018-C3		0.88±0.15		1.78±0.20		2.21±0.24
B	0.87		1.77		2.16	
A	0.86		1.68		2.20	
OK73.08		0.84±0.13		1.75±0.21		2.19±0.27
B	0.81		1.82		2.18	
A	0.76		1.55		1.58	
55018-C1		0.67±0.12		1.62±0.22		1.64±0.20
B	0.58		1.68		1.69	
A	0.62		1.11		1.24	
48018RCR		0.59±0.15		1.01±0.21		1.24±0.20
B	0.56		0.91		1.24	
A	0.83		1.66		1.89	
EL12/F4803						
B	0.84		1.61		1.82	
A	0.6		1.08		1.89	
Plate						
B	0.6		1.12			

A - high heat input
B - low heat input

Table 4: Depth of HAZ corrosion after 6 months (mm)

Plate	Consumables	High Heat Input	Low Heat Input
E	48018-1	------	------
	48018RCR	1.68	1.80
	55018-C1	1.60	1.55
	55018-C3	------	0.38
	OK73.08	0.20	0.33
EH	48018-1	0.28	0.28
	48018RCR	2.13	2.40
	55018-C1	2.26	2.29
	55018-C3	1.35	1.14
	OK73.08	0.99	0.99

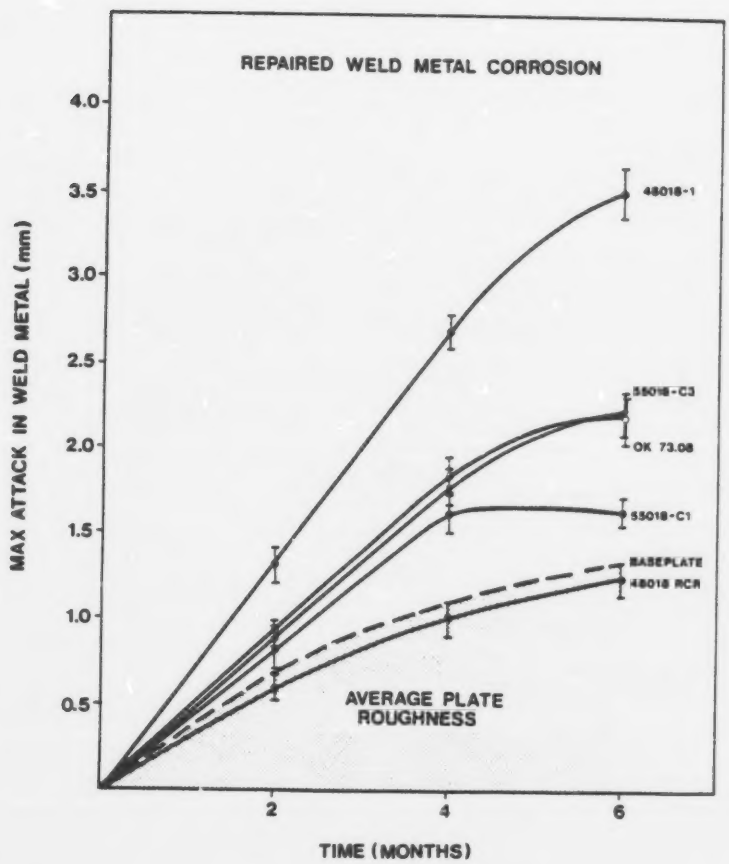

Fig. 1 Corrosion rates of shielded metal arc repair welds on Grade A, Grade E and Grade EH plate

Fig. 2 Photograph of ridge morphology which developed in one week of tank testing at 30 C. Maximum depth of attack is approximately 0.5 mm.

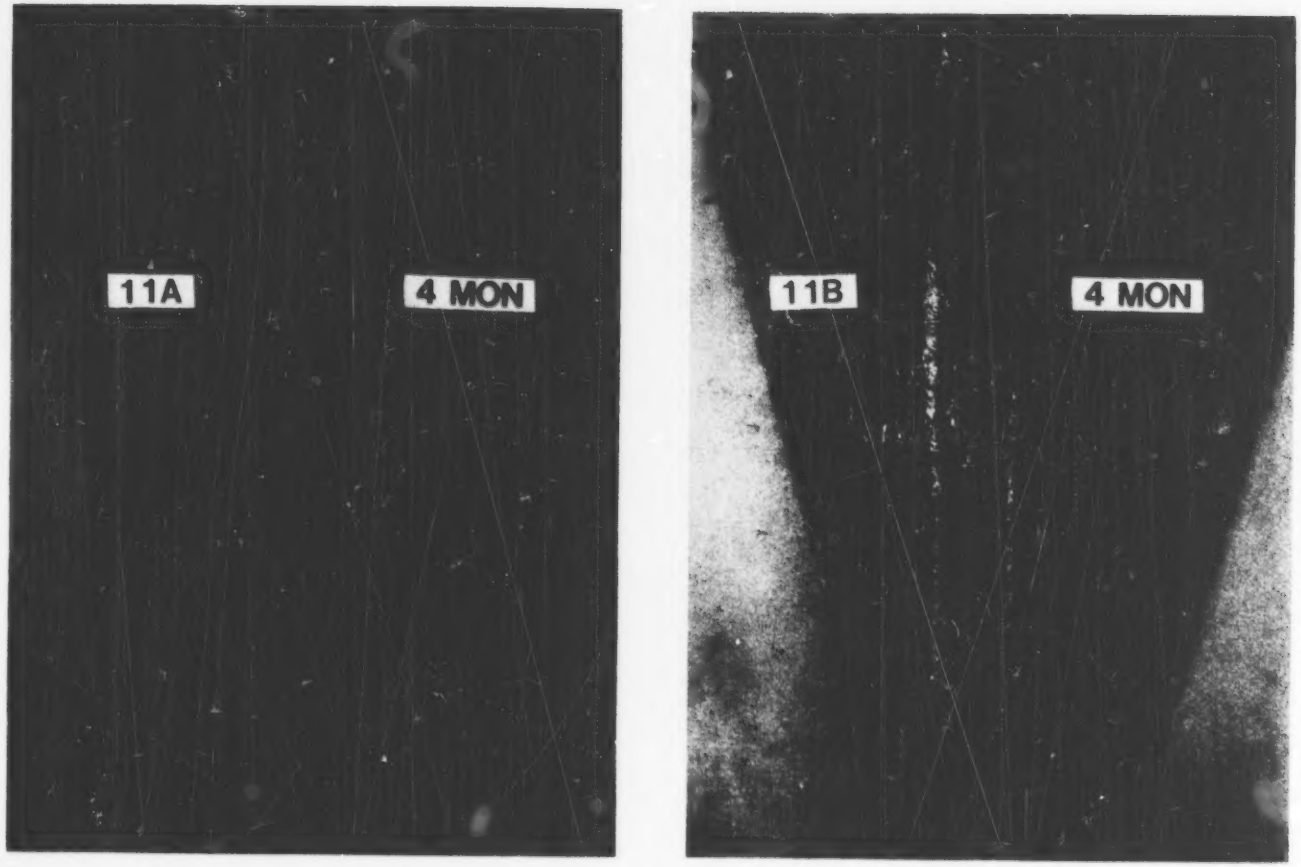

Fig. 3 Photographs of Grade EH steel samples repaired with 48018 RCR SMAW electrode (11A at high and 11B at low heat input) after a 4 month tank test exposure.

Fig. 4 Photographs of Grade A steel samples repaired with 48018-1 SMAW electrode (1A at high and 1B at low heat input) after a 4 month tank test exposure.

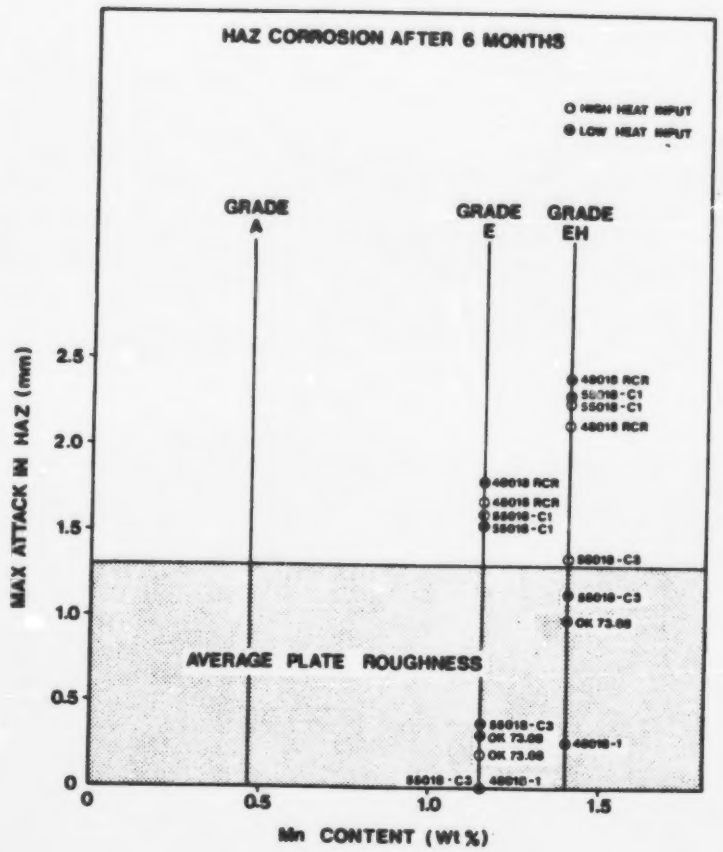

Fig. 5 Depth of attack in the heat affected zone of Grade E and EH steel plates as a function of Mn content of the plate. Grade A plate showed no preferential HAZ attack.